Tillage System, Fertilizer Nitrogen Rate, and Timing Effect on Corn Yields in the Texas Blackland Prairie

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ABSTRACT

New N management and conservation tillage systems are needed to improve agricultural sustainability on the Blackland Prairie of Texas. In 1994, an experiment was established to determine plant response to N fertilizer rate and timing within three different tillage systems. A split plot experiment with four replications was established on a Houston Black clay (fine, smectitic, thermic Udic Haplusterts) soil. The main plots were chisel tillage system without beds (conventional for the area), chisel tillage system with raised wide beds, and no-tillage system with raised wide beds. The subplots were seven fertility treatments: four fertility rates (0, 56, 112, and 168 kg N ha^{-1} applied at planting) and three timing treatments (N applied in the fall, at planting, and split between at planting and 30 d later). The crop rotation was wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), and sorghum [*Sorghum bicolor* (L.) Moench]. The experimental treatments were imposed on corn each year for 4 yr. Plant samples were collected for grain yield, biomass production, and N uptake. Grain yield ranged from 150 to 8435 kg ha^{-1}. In wet years, grain yields and N uptake increased with N fertilizer up to 168 kg N ha^{-1}, and fall application reduced yields 30% when compared with fertilizer application at planting. The highest yields were observed with the no-tillage. Results from this study indicate that application of fertilizer in the fall may result in lost yield potential and that conservation tillage systems may be the most reliable in the Texas Blackland Prairie.

Tillage systems are an integral part of crop production affecting numerous factors important to crop growth. Recently, a shift toward conservation-tillage systems has occurred for a variety of reasons, including soil water conservation, fuel energy savings, erosion control, and government erosion compliance regulations. For these reasons, efforts have been undertaken to develop conservation tillage systems for the soils of the Texas Blackland Prairie.

Vertisols, in the Blackland Prairie, are difficult to manage because of their physical characteristics, including high shrink–swell potential, high water holding capacity, high plasticity, increased strength when dry, and a limited range of soil water content in which soil tillage can be performed (Potter and Chichester, 1993). When wet, these soils have slow infiltration rates, which can lead to high runoff rates; because such soils slake into fine aggregates, they are easily eroded by water. The most common tillage system used in this region for corn production has been a chisel tillage system. A management system using raised wide beds has been proposed as a conservation tillage system for these soils (Morrison et al., 1990). Furrows between the wide beds were used as surface drain ways and controlled-traffic lanes. This system has been found to support corn grain yields comparable to the conventional chisel tillage systems (Potter et al., 1996), but the influence of these soil tillage systems on fertilizer N management has not been determined.

Fertilizer N management can be greatly affected by changes in tillage. For example, conservation tillage systems may increase both N immobilization (Gilliam and Hoyt, 1987) and N losses from leaching (Tyler and Thomas, 1977) and denitrification (Gilliam and Hoyt, 1987). Soil moisture and temperature, which are greatly affected by tillage, will also impact soil N dynamics (Torbert and Wood, 1992; Nadelhoffer et al., 1991). The use of conservation tillage has been reported to increase short-term N immobilization due to the slower plant decomposition process when tillage is limited (Gilliam and Hoyt, 1987; Wood and Edwards, 1992). Generally, in conservation tillage fertilizer N rates have been increased by as much as 25% to prevent yield limitations from short-term N immobilization (Randall and Bandel, 1991). It has been hypothesized that application efficiency of fertilizer N can be enhanced by synchronizing fertilizer application with plant uptake needs (Keeney, 1982). Fertilizer applied during peak plant N demand can limit fertilizer N immobilization and/or losses from the soil–plant system due to leaching and denitrification and to increase N use efficiency (Olson and Kurtz, 1982; Keeney, 1982). Synchronization of residue N mineralization, fertilizer-N application time, and subsequent crop demand for N can improve N use efficiency of crops planted in conservation tillage systems (Reeves et al., 1993). Studies conducted on C and N cycling in Vertisols have shown that changes in potential N mineralization levels were impacted more due to changes in tillage intensity than fertility management (Torbert et al., 1997), but the influence of these soil tillage systems on fertilizer N rates or timing on corn production in Vertisols of the Blackland Prairie has not been determined.

In addition, in the Blackland Prairie, the soil and climate conditions that make managing the soil physical

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Abbreviations: Chisel-bed, chisel plow tillage system with bedding; chisel–no bed, chisel plow tillage system without bedding; no-till, no-tillage system with bedding.

properties difficult also cause difficulties with fertilizer N management. For example, substantial losses of fertilizer nutrients could occur with surface application of granular fertilizer under wet soil conditions (Torbert et al., 1999). Using simulated rainfall on a chisel plowed field, Torbert et al. (1999) reported an increase of 3.0 to 18.9 kg NH_4–N ha^{-1} losses in a runoff event when fertilizer was applied to wet soil (0.30 kg kg^{-1} soil) when compared to dry soil (0.10 kg kg^{-1} soil). Covering the soil with residue reduced NH_4–N losses from 18.9 to 3.9 kg ha^{-1}. Physical restraints due to the soil and climate conditions also impact fertilizer application management due not only to the limited time for field operations, but also to the interaction of application equipment with the physical condition (i.e., stickiness) of soil (Morrison and Chichester, 1988; Morrison and Potter, 1994). Because soil conditions are usually wet during planting operations, fertilizer N commonly is applied during the fall or early winter to expedite field operations. However, the potential fertilizer N loss during this fallow period and the impact on crop yields due to these losses is not well understood.

The sustainability of any crop production system depends on maintaining adequate soil plant nutrients such as N. To fully develop conservation tillage systems for the soils of the Texas Blackland Prairie an understanding of the dynamics of applied N fertilizer in this new conservation tillage system is needed. The objectives of this study were: (i) to investigate the impact of tillage systems on fertilizer N application rates needed; and (ii) to examine the impact of fertilizer application timing within these tillage systems on corn production.

MATERIALS AND METHODS

This study was conducted from 1994 through 1997 at the Grassland, Soil and Water Research Laboratory, at Temple, TX (31°05′N, 97°20′W) on a Houston Black (fine, smectitic, thermic Udic Haplusterts) clay soil. The experimental design was a split-plot within a randomized complete block with four replications. The main-plots were three tillage systems and the subplots were seven fertilizer N treatments. This study was imposed on an existing tillage study consisting of no tillage and chisel tillage systems that had been maintained for 8 yr previous to the initiation of the N management study.

Tillage plots (244 m long and 18.3 m wide) consisted of either a chisel plow tillage system with bedding (chisel-bed), chisel plow without bedding (chisel–no bed), or a no-tillage system with bedding (no-till). The chisel–no bed system consisted of flail-shredding residue, tandem disking, chisel tilling, tandem disking, and field cultivating. This system is the most common management system in the area. The no-till system consisted of no preplant tillage and planting with a slot planter. Percent residue cover for the wheat residue (residue into which corn was planted) in this study was reported at 99.3% with a standard deviation of 1.5 for the no-till treatment, while the chisel-till treatment resulted in a 30.0% residue cover with an 8.6 standard deviation (Torbert et al., 1996; Morrison et al., 1996). In the chisel–no bed and the no-till systems, the beds were raised soil areas 0.15 m high, 1.5 m wide, and each was separated by 0.5-m furrows (Morrison et al., 1990). In the chisel-bed system, the beds were chisel plowed annually and then reconstructed each year. Once every 3 yr in the no-till system, the furrows between the wide beds were maintained with a sweep that cleaned the furrow and reformed the bed shoulder.

Table 1. Growing season monthly rainfall and 30-yr normal monthly rainfall.

	1994	1995	1996	1997	Normal
			mm		
February	83	23	0.3	129	72
March	37	91	62	54	67
April	77	91	49	243	81
May	141	136	127	128	122
June	52	75	64	105	93
July	18	67	24	57	48
August	67	36	129	20	59
Total	475	521	456	736	542

Crop production in these plots consisted of an annual rotation of wheat (*Triticum aestivum* L.), followed by corn (*Zea mays* L.), which was followed by grain sorghum [*Sorghum bicolor* (L.) Moench]. Corn row spacing was 76 cm. A starter fertilizer (10–34–0 solution) placed adjacent to the seed at planting provided 5.6 kg N ha^{-1} and 19.1 kg P ha^{-1} to all treatments. Yearly fertilizer N applications previous to initiation of this study were 168 kg ha^{-1} applied to corn, 140 kg ha^{-1} applied to grain sorghum, and 112 kg ha^{-1} applied to wheat. All three crops were present in the study each year, but only corn will be discussed. Corn was planted on 3 Mar. 1994, 23 Feb. 1995, 21 Feb. 1996, and 31 Mar. 1997 at a rate of 66 700 seed ha^{-1}.

The main plots were split into seven fertilizer N management treatments, each of 30.5 m in length and 4 m wide, which included four fertilizer N rate and three fertilizer N application timing treatments. Fertilizer N rate treatments consisted of 0, 56, 112, and 168 kg N ha^{-1} applied at planting. Fertilizer N application timing treatments included applying 168 kg N ha^{-1} in the fall, at planting, or a split fertilizer N application consisting of 112 kg N ha^{-1} applied at planting and 56 kg N ha^{-1} applied 30 d after planting. Liquid UAN (urea ammonia nitrate, 32–0–0) was applied in a low-disturbance band with a coulter-nozzle applicator, which placed the fertilizer in the surface 5 cm of soil with complete soil coverage of the fertilizer band (Morrison and Potter, 1994). Similar fertilizer N application treatments were applied in the wheat and grain sorghum crop rotations at rates appropriate for each crop to maintain a continuity of fertilizer N treatment plots (data not shown).

At harvest, plant samples were collected for grain and fodder yield by collecting above ground biomass from a total of 5.9 m of row. Plants were collected from across the entire width of the wide bed to account for any difference due to proximity to the furrow. Plant samples were separate for grain and fodder, dried at 65°C (until weight loss was complete), ground to pass a 0.15-mm sieve, and analyzed for total N on a FISON NA1500 nitrogen and carbon determinator (Fison Instruments, Dearborn, MI[1]). Total biomass and total N uptake were calculated as the sum of the grain and fodder components.

Statistical analysis of data were performed using the Mixed procedure of the Statistical Analysis System at an established a priori level of $P \leq 0.10$ (SAS Inst., 1996).

RESULTS AND DISCUSSION

Weather conditions were variable during the 4 yr of the study (Table 1). Total rainfall during the growing

[1] Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the production, the use of the name by USDA implies no approval of the product to the exclusion of others that may be suitable.

Table 2. Effect of tillage system on corn biomass yield and total N uptake (kg ha^{-1}).†

	Biomass yield			N uptake		
Year	**Chisel–no bed**	**Chisel-bed**	**No-till**	**Chisel–no bed**	**Chisel-bed**	**No-till**
	kg ha^{-1}					
1994	**7 677a**	**7 672a**	**10 465b**	**82.5a**	**83.8a**	**96.6a**
1995	**8 122a**	**12 072b**	**11 456c**	**82.2a**	**105.4b**	**111.4c**
1996	**2 138a**	**4 366b**	**5 979c**	**23.1a**	**51.6b**	**60.9c**
1997	**10 788a**	**11 496a**	**11 633a**	**94.1a**	**107.2b**	**106.2b**

† Values represent means of four replications. Means within a year for biomass yield or N uptake followed by the same letter do not differ significantly (α = 0.1).

season ranged from 456 mm in 1996 to 737 mm in 1997. These variations resulted in wide differences in corn biomass and grain yields, both between years and between the tillage and fertility treatments (Tables 2, 3, 4, and 5). Low corn production in 1994 and 1996 (Tables 2 and 3) resulted from low rainfall totals (Table 1). High corn production was recorded in 1995, while exceptional growing conditions resulted in very high corn production for the region in the experiment in 1997 (Tables 2 and 3).

In 1994, no-till had higher biomass production than the chisel-bed or chisel–no bed systems (Table 2). This increase in total biomass production led to a small increase in grain yield production with a significant differences between means observed for the no-till system compared to the chisel–no bed system (Table 3). In 1994, low rainfall in addition to reduced plant stands may have reduced yield responses to tillage (as was observed in similar tillage studies in adjacent areas by Potter et al., 1996). No significant difference between the tillage systems was observed for N uptake as measured in the grain or in total biomass in this year (Tables 2 and 3).

In the dry 1996 year, as was observed in 1994, the lowest biomass yields were observed with the chisel–no bed treatment and the highest yields were observed with the no-till treatment. This increase in biomass production also resulted in a corresponding increase in grain yields. While grain yields in 1996 were reduced when compared with other years (especially the wetter years), the no-till treatment provided a yield advantage when compared with chisel–no bed and the chisel-bed treatments (Table 3). Similar effects were observed for N uptake between the tillage treatments in 1996 for both the grain and total biomass measurements (Tables 2 and 3). The yield advantage observed in both biomass and grain production with the no-till treatment when compared to the chisel tillage treatments in the dry years of 1994 and 1996 was most likely due to the 99.3% residue ground cover, which would have reduced soil water evaporation and increased soil water conservation.

In the 2 yr with higher rainfall (1995 and 1997), biomass production was higher when compared with the dry years and differences between tillage systems were smaller (Table 2). In 1995, the chisel-bed system had the highest biomass production and chisel–no bed had the lowest yields. No significant difference was observed for biomass production between tillage treatments in 1997 (Table 2). However, differences were observed in total N uptake between the different tillage treatments in the 2 wet years (Table 2). In both 1995 and 1997, the chisel–no bed treatment had lower N uptake when compared with the bedded treatments, and in 1995 the no-till system had higher total N uptake when compared with the other tillage systems (Table 2).

As with biomass production, grain yields were higher in the higher rainfall years (1995 and 1997) than the low rainfall years (1994 and 1996) (Table 3). In 1995 and 1997, the chisel–no bed treatment had lower yields than the no-till treatments (Table 3). Similarly, N uptake in grain mirrored these differences (Table 3).

In almost all cases, the chisel–no bed treatment resulted in numerically lowest yield and N uptake in both grain and biomass (Tables 2 and 3). Likewise, the highest numeric yields and N uptake were observed with the no-tillage system. This indicated that a yield advantage may be realized by using a tillage system that utilized soil bedding in the heavy clay soils of the Blackland Prairie. Likewise, this also indicates that the no-tillage system may be the most reliable tillage system for corn production in this region.

Corn response to fertilizer N application rate was highly dependent on the rainfall conditions. In the two low rainfall years (1994 and 1996), limitations to plant growth resulted in a limited effect for fertilizer N application in corn biomass production (Table 4). In both 1994 and 1996, only the no-till treatment had a positive

Table 3. Effect of tillage system on corn grain yield and N uptake (kg ha^{-1}).†

	Grain yield			N uptake		
Year	**Chisel–no bed**	**Chisel-bed**	**No-till**	**Chisel–no bed**	**Chisel-bed**	**No-till**
	kg ha^{-1}					
1994	**3012a**	**3481ab**	**4213b**	**46.7a**	**41.9a**	**62.5a**
1995	**4282a**	**6644b**	**6661b**	**56.2a**	**75.2b**	**81.0c**
1996	**359a**	**909b**	**2106c**	**5.5a**	**13.3b**	**29.0c**
1997	**6501a**	**6930ab**	**7157b**	**76.6a**	**83.0ab**	**84.2b**

† Values represent means of four replications. Means within a year for grain yield or N uptake followed by the same letter do not differ significantly (α = 0.1).

Table 4. Effect of tillage system and N fertilizer rate on biomass yield and N uptake (kg ha^{-1}).†

	Chisel–no bed		Chisel-bed		No-till–bed	
Fertilizer N rate	Biomass	Total N	Biomass	Total N	Biomass	Total N
	kg ha^{-1}					
			1994			
0	5 755a	52.1a	6 287a	64.1a	7 776a	58.5a
56	6 967a	73.3ab	9 453b	88.3a	9 231ac	77.6ab
112	7 595a	86.8b	7 828ab	80.3a	11 799b	108.6b
168	7 069a	80.1ab	6 931a	74.4a	11 207bc	100.8b
			1995			
0	6 894a	56.2a	7 015a	49.5a	8 561a	61.3a
56	7 761ab	69.5ab	11 668b	90.0b	9 940b	80.8b
112	7 403ab	76.1b	12 638bc	108.5c	13 169c	122.2c
168	9 734b	98.7c	13 386c	126.1d	12 651c	131.2c
			1996			
0	3 261a	29.9a	4 617a	31.8a	5 079a	36.7a
56	2 207a	25.0a	3 925a	39.8a	5 095a	47.1ab
112	1 844a	21.0a	3 805a	45.3ab	6 416ab	65.8bc
168	1 867a	22.5a	5 126a	65.5b	6 927b	71.7c
			1997			
0	7 201a	47.1a	7 074a	54.6a	9 815a	85.7a
56	10 065b	76.9b	11 140b	93.9b	10 336a	84.8a
112	11 160bc	98.7b	10 333b	80.9ab	11 392a	107.4ab
168	13 129c	125.3c	14 355c	144.1c	14 240b	129.4b

† Values represent means of four replications. Means within a column followed by the same letter do not differ significantly (α = 0.1).

response to increasing N fertilizer for biomass production (Table 4). In 1994, the increased N application rates increased N uptake with the no-till system. A significant increase in N uptake was also observed for the chisel–no bed treatment, although no increase in biomass production was observed. With the chisel-bed treatment, there was no significant effect for either biomass production or N uptake with fertilizer rate treatments (Table 4). Again, in 1996 only the no-till treatment had a significant response to N fertilizer application for biomass production, and a positive response for fertilizer N application in total N uptake for the no-till treatment (Table 4). A significant increase in N uptake was observed for the chisel-bed treatment, but this increase did not result in a significant increase in biomass production for this treatment. No significant effect was observed for either biomass or total N uptake for the chisel–no bed treatment (Table 4).

In the 2 yr with higher rainfall conditions, a significant increase was observed for biomass production and total N uptake with increased fertilizer N application in all tillage systems (Table 4). In general, fertilizer N application up to 168 kg ha^{-1} increased both the biomass yield and N uptake in both years (Table 4).

Grain yield and grain N uptake response was severely limited in the 2 dry years, with no significant effect to increasing N application with any of the tillage treatments for either 1994 or 1996 (Table 5). The small fertilizer N response that was observed for total biomass production and total N uptake in these 2 yr (Table 4) was not observed as a N response for grain production (Table 5).

In both 1995 and 1997, increasing fertilizer N rate increased corn yield within all of the tillage systems up to 168 kg ha^{-1} (Table 5). Likewise, N uptake in grain increased with increasing N application in 1995 and 1997 (Table 5). Generally, the larger the yield response from tillage systems, the more positively corn yields increased with increasing fertilizer N. For example in 1995, grain yield in chisel–no bed increased from 3601 to 4809 kg ha^{-1} while no-till increased from 4161 to 7612 kg ha^{-1} for fertilizer application of 0 to 168 kg N ha^{-1}, respectively. Similar results were observed in 1997, with an increase of 3929 to 8303 kg ha^{-1} for chisel-bed and 6094 to 8435 kg ha^{-1} for fertilizer N application of 0 to 168 kg ha^{-1}, respectively.

Conversion to conservation tillage has been reported to increase short-term N immobilization, and therefore, to prevent yield losses due to N stress, many agronomist recommend that fertilizer rates should be increased (Randall and Bandel, 1991; Wood and Edwards, 1992). In our study, there was no indication that short-term N immobilization reduced yield in the no-till system (Table 5). Even at the lower N rates, no reduction in yields were observed in the no-till compared with the chisel tillage systems in any year (Table 5). In fact, in 1997 the no-till resulted in a significant increase of grain yield compared with the chisel tillage treatments with 6094 kg grain ha^{-1} for no-till compared with 3929 kg grain ha^{-1} (P = 0.015) for chisel-bed and 4217 kg grain ha^{-1} (P = 0.034) for chisel–no bed. Likewise, no effect was observed for N uptake with the use of no-till compared with the chisel tillage systems, including the 2 yr that where highly responsive to fertilizer N application (Table 5). In fact, as was observed with grain yield, end of the year N uptake in grain was significantly increased in no-till compared with the chisel tillage systems, even when no fertilizer N was applied, with 70 kg N ha^{-1} for no-till compared with 43 kg N ha^{-1} (P = 0.023) for chisel-bed and 40 kg N ha^{-1} (P = 0.010) for chisel–no bed. If a short-term N immobilization occurs in these systems it is not sufficient to either reduce N uptake or to decrease grain yields by the end of the growing season. It is note worthy to remember that these were well established no-till systems that had been in place for 8 yr previous to the establishment of this fertilizer N study.

Table 5. Effect of tillage system and N fertilizer rate on corn grain yield and N uptake (kg ha^{-1}).†

Fertilizer N rate	Chisel–no bed Yield	Chisel–no bed N	Chisel-bed Yield	Chisel-bed N	No-till–bed Yield	No-till–bed N
	kg ha^{-1}					
1994						
0	2304a	35.1a	3180a	37.6a	3296a	35.7a
56	2956a	48.1a	4040a	47.2a	3593a	39.7a
112	2783a	47.1a	3245a	40.9a	4794a	53.2a
168	3060a	48.3a	3012a	40.3a	4452a	53.1a
1995						
0	3601a	39.2a	3639a	34.0a	4161a	40.3a
56	3886a	48.8b	6065b	60.6b	5641b	58.8b
112	4124a	54.2b	6970c	77.0c	7541c	89.1c
168	4809b	64.2c	7711c	93.1d	7612d	94.2c
1996						
0	1180a	16.9a	1306a	15.7a	2072a	24.6a
56	150a	2.4a	665a	9.5a	2626a	34.1a
112	161a	2.5a	589a	9.0a	1978a	28.6a
168	488a	7.9a	1220a	18.5a	2067a	29.1a
1997						
0	4217a	39.5a	3929a	43.3a	6094a	70.0a
56	5881b	63.9b	6593b	75.0b	6494a	69.4a
112	6871bc	81.8bc	6204b	67.4b	7137ab	87.2ab
168	8012c	99.9c	8303c	106.2c	8435b	102.0b

† Values represent means of four replications. Means within a column followed by the same letter do not differ significantly (α = 0.1).

Table 6. Effect of tillage system and fertilizer N timing on corn grain yield and N uptake (kg ha^{-1}).†

N fertilizer timing‡	Chisel–no bed Grain	Chisel–no bed N	Chisel-bed Grain	Chisel-bed N	No-till–bed Grain	No-till–bed N
	kg ha^{-1}					
1994						
0	3060a	48.3a	3012a	40.3a	4452a	53.1a
Split‡	3229a	44.5a	3983a	77.2b	4352a	53.8a
Fall	3273a	45.2a	3595a	44.7a	4632a	51.9a
1995						
Planting	4809a	64.2a	7711a	93.1a	7612a	94.2a
Split‡	4412ab	60.3a	7459a	90.9a	7098a	91.3a
Fall	3917b	57.9a	5822b	60.0b	6106b	70.9b
1996						
Planting	488a	7.9a	1220a	18.5a	2067a	29.1a
Split‡	56a	0.9a	1297a	19.4a	2184a	31.2a
Fall	393a	6.1a	566a	9.1a	2096a	30.3a
1997						
Planting	8012a	99.9a	8303a	106.2a	8435a	102.0a
Split‡	7121ab	88.3a	8352a	105.6a	9854a	118.6a
Fall	5904b	63.7b	5871b	66.0b	4353b	44.0b

† Values represent means of four replications. Means within a column followed by the same letter do not differ significantly (α = 0.1).
‡ Fertilizer application was 168 kg N ha^{-1}; split = split fertilizer N application with 112 kg ha^{-1} applied at planting and 56 kg ha^{-1} applied approximately 30 d later.

It is likely that the short-term N imbalance in no-till systems compared with conventional tillage systems does not prevail long term. The data from this study indicates that for well-established no-till systems in the Blackland Prairie, there is no need to increase fertilizer N application rate to compensate for N immobilization.

In this heavy clay soil, splitting the N applications did not increase yield (Table 6). Even in the 2 wet years (1995 and 1997) when corn yield responded well to increased N fertilizer application rates, no significant impact to split application was observed and in general, a numerical reduction in yield was observed with the split N application in all the tillage treatments for the 4 yr of the study (Table 6). Likewise, no significant increase in N uptake was observed from applying split application of 56 kg ha^{-1} after planting (except for chisel-bed in 1994) (Table 6). This indicates that N availability was not greatly limiting plant N uptake or grain yields in the no-till system when compared with the chisel tillage systems. This is further evidence that in this soil, short-term N immobilization either did not occur or has no lasting effect over the growing season on corn production. Further, this data would indicated that the extra expense incurred with time and equipment with split fertilizer N applications would not be warranted.

In the two good production years (1995 and 1997), applying fertilizer N in the fall reduced yields across tillage treatments 21% in 1995 and 34% in 1997 (Table 6). Nitrogen uptake was also significantly reduced with fall application of fertilizer N compared with application at planting or split applied in those years when a yield reduction was noted (Table 6). This would indicate that the observed yield reductions were caused by N limitations to plant growth.

The N uptake reduction observed in this study with the fall N application treatment was most likely due to soil N loss mechanisms during the winter fallow period before planting (i.e., leaching, erosion, denitrification). In these heavy clay soils, water movement through the soil profile is generally very slow (Potter et al., 1995); therefore, N leaching is normally considered to be nonconsequential. However, differential water flow through soil cracks may greatly contribute to water recharge of the soil profile (Potter et al., 1995), and therefore, could contribute to some N losses from the soil through leaching. Soil erosion may have also contribute to N losses. However, fertilizer N losses from erosion were likely very small since the N uptake reduction observed was as prevalent in the no-till treatment where erosion would be greatly reduced compared with the chisel tillage systems (Torbert et al., 1996). The largest N losses were most likely due to denitrification, since all of the soil conditions required for denitrification were present during the fallow winter period (Ryden and Lund, 1980; Mulvaney and Kurtz, 1984). For example, following fall fertilizer N application in this region soil conditions are commonly saturated and soils temperatures are only rarely below freezing. In addition, these soil are calcareous and denitrification is promoted by elevated soil pH levels. Also, in these tillage systems, the residue of the previous year's crop would provide a readily available soil C source for microbial activity.

Yield losses caused by fall N application were greatest in years with the highest yield potential. For example, the greatest yield levels observed in this study were for the no-till treatments in 1997. In 1997, fall N application to corn grown in no-till resulted in a 48% reduction in yield compared with fertilizer N application at planting (Table 6). The greatest impact to the farmer for expediting fertilizer N application with fall application would be in losing yield potential in those few years when growing conditions were optimal.

CONCLUSION

The results from this study indicate that corn yields in the Texas Blackland Prairie may respond positively to planting corn rows on beds and particularly to a change to a conservation tillage system. There was no indication of N limitations in the no-till system compared to the other tillage systems, indicating that there was no need to increase N application rates when using well established conservation tillage systems. While no benefit was realized from split application of fertilizer N after planting, large reductions in corn yields were observed with fall application of fertilizer N in wet years. In this study, the highest yields were observed with the no-till system indicating that a conservation tillage system may be the most reliable tillage system in these Vertisol soils.

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